

APPLICATION  
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TITLE: OPTICAL MODULE

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TITLE OF THE INVENTION

OPTICAL MODULE

BACKGROUND OF THE INVENTIONField of the Invention

5 [0001] The present invention relates to an optical module.

Related Background Art

[0002] An optical module includes a semiconductor laser element. The semiconductor laser element generates an optical signal in response to an externally applied electric signal. In one example, the optical modules together with a driving element are provided on a printed circuit board. The driving element generates an electric signal for driving the optical module. Optical modules have a variety of uses and are used in optical communication systems, such as trunk optical communication systems and in metro optical communication systems.

SUMMARY OF THE INVENTION

20 [0003] In order to implement fast optical communications, optical modules are required to operate at higher transmission rates. With the increasing range of applications of optical communications, these applications need low-priced optical modules. In the recent optical communications, the optical modules are required to

generate optical signals of transmission rates as high as several gigabits per second.

[0004] It is an object of the present invention to provide an optical module having a structure enabling 5 the monitoring of a forward light from a semiconductor light emitting element driven by a driving element for generating a drive signal.

[0005] According to one aspect of the present invention, an optical module comprises: a substrate, a 10 semiconductor light emitting device, a semiconductor light receiving device, and an optical device. The substrate has first and second regions and first and second optical waveguides. The first and second regions are arranged along a predetermined plane. The 15 first and second optical waveguides is provided in the first region. The first and second optical waveguides extend in a direction of a predetermined axis. The semiconductor light emitting device includes a semiconductor light emitting element. The 20 semiconductor light emitting device is provided in the second region. The semiconductor light emitting element is optically coupled to the second optical waveguide. The semiconductor light receiving device includes a light receiving element. The semiconductor 25 light receiving device is provided in the first region. The optical device includes an optical

element. The optical element is provided on the first region so as to reflect a part of incident light from the light emitting element to the light receiving element and so as to transmit a part of the incident light. The light receiving element is optically coupled to the optical element. The optical element is provided between the first and second optical waveguides. The optical element is optically coupled to the first and second optical waveguides.

[0006] The optical module further comprises a semiconductor driving element and a mount member. The semiconductor driving element is electrically connected to the semiconductor light emitting element. The semiconductor driving element is mounted on the mount member. The substrate and the mount member are arranged along the predetermined plane.

[0007] The optical module further comprises a semiconductor driving element electrically connected to the semiconductor light emitting element. The substrate has a third region. The first to third regions are arranged along the predetermined plane. The semiconductor driving element is provided in the third region of the substrate.

[0008] In the optical module, the substrate further includes at least one third optical waveguide and at least one fourth optical waveguide. The third optical

waveguide and the fourth optical waveguide extend in a direction of another predetermined axis. The semiconductor light emitting device further includes another semiconductor light emitting element provided in the second region. The fourth waveguide is optically coupled to the other semiconductor light emitting element. The optical device further includes another optical element provided between the third and fourth optical waveguides. The semiconductor light receiving device further includes another light receiving element provided in the first region. The other semiconductor light emitting element is electrically connected to the semiconductor driving element. The other optical element is optically coupled to the third and fourth optical waveguides. The other optical element is provided on the first region so as to reflect a part of incident light from the other light emitting element to the other light receiving element and so as to transmit a part of the incident light. The other light receiving element is optically coupled to the other optical element. The other optical element is provided between the third waveguide and the fourth waveguide.

[0009] In the optical module, the substrate includes a groove provided in the first region. The substrate has a pair of edges extending in the

direction of the predetermined axis. The groove extends from one of the pair of edges to the other and extends along a reference plane intersecting with the predetermined plane. The optical device is provided  
5 in the groove.

[0010] In the optical module, the optical axis of the first optical waveguide extends along a reference axis. The reference axis forms an acute angle with the reference plane.

10 [0011] In the optical module, the first region has a primary surface. The primary surface has a first area and a second area. The first waveguide is located in the first area, and the second waveguide is located in the second area. The semiconductor light receiving device is located on the second area.  
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[0012] In the optical module, the optical device has a transparent substrate. Light from the semiconductor light emitting element can pass through the transparent substrate. The transparent substrate  
20 has a pair of surfaces, each extending along a plane intersecting with the predetermined axis. One of the pair of surfaces is inclined so as to reflect a part of incident light from the light emitting element to the light receiving element.

25 [0013] According to another aspect of the present invention, an optical module comprises a substrate, a

first optical fiber, a second optical fiber, a semiconductor light emitting device, a semiconductor driving element, an optical device, and a semiconductor light receiving device. The substrate having first and second regions are arranged along a predetermined plane. The first optical fiber is provided in the first region of the substrate. The first optical fiber extends in a direction of a predetermined axis. The second optical fiber is provided in the first region of the substrate. The second optical fiber extends in the direction of the predetermined axis. The semiconductor light emitting device is provided in the second region. The semiconductor light emitting device includes a semiconductor light emitting element. The semiconductor light emitting element is optically coupled to the second optical fiber. The semiconductor driving element is electrically connected to the semiconductor light emitting element. The optical device includes an optical element. The optical element is provided on the first region so as to reflect a part of incident light and so as to transmit a part of the incident light. The semiconductor light receiving device includes a light receiving element. The light receiving element is provided in the first region. The light receiving

element is optically coupled to the optical element. The optical element is provided between the first optical fiber and the second optical fiber. The optical element is optically coupled to the first optical fiber and to the second optical fiber.

5 [0014] The optical module further comprises a mount member. The semiconductor driving element is mounted on the mount member. The mount member and the substrate are arranged along the predetermined plane.

10 [0015] In the optical module, the substrate further includes a third region. The first to third regions are arranged along the predetermined plane. The semiconductor driving element is provided on the third region.

15 [0016] The optical module further comprises at least one third optical fiber and at least one fourth optical fiber. The third optical fiber and the fourth optical fiber extend in a direction of another predetermined axis. The semiconductor light emitting device further includes another semiconductor light emitting element is provided in the second region. The other semiconductor light emitting element is optically coupled to the fourth optical fiber. The semiconductor light receiving device further includes another light receiving element provided in the first region. The optical device further includes another

optical element provided between the third and fourth optical fibers. The other optical element is provided on the first region so as to reflect a part of incident light from the other light emitting element  
5 to the other light receiving element and so as to transmit a part of the incident light. The other optical element is optically coupled to the third and fourth optical fibers. The other light receiving element is optically coupled to the other optical element.  
10 The other semiconductor light emitting element is electrically connected to the semiconductor driving element.

[0017] In the optical module, the first region has a primary surface. The primary surface has a first area and a second area. The first and second areas are arranged along the predetermined axis. The first optical fiber is located in the first area. The second optical fiber is located in the second area. The semiconductor light receiving device is located on  
15 the second area.  
20

[0018] In the optical module, the second fiber is provided between the light receiving element and the substrate.

[0019] The optical module further comprises a mount  
25 part. The semiconductor light receiving device is mounted on the mount part. The second optical fibers

is provided between the mount part and the substrate.

[0020] In the optical module, the substrate includes a groove provided in the first region. The substrate has a pair of edges extending in the direction of the predetermined axis. The groove extends from one of the pair of edges to the other and extends along a reference plane intersecting with the predetermined plane. The optical device is provided in the groove.

10 [0021] In the optical module, the optical axis of the first optical fiber extends along a reference axis. The reference axis forms an acute angle with the reference plane.

15 [0022] In the optical module, the optical device has a transparent substrate. Light from the semiconductor light emitting element can pass through the transparent substrate. The transparent substrate has a pair of surfaces, each extending along a plane intersecting with the predetermined axis. One of the 20 pair of surfaces is inclined so as to reflect a part of incident light from the light emitting element to the light receiving element.

25 [0023] In the optical module, the optical device has a transparent substrate and a dielectric multilayer film. Light from the semiconductor light emitting element can pass through the transparent

substrate. The dielectric multilayer film is provided on the transparent substrate. One of the pair of surfaces is inclined so as to reflect a part of incident light from the light emitting element to the 5 light receiving element.

[0024] The optical module further comprises a transparent resin. The transparent resin is provided on the substrate so as to cover the semiconductor light emitting element, the light receiving element, 10 and the optical element. Light from the semiconductor light emitting element can pass through the transparent resin.

[0025] In the optical module, the light receiving element has a light entrance surface which receives light from the optical element. The light receiving element is located such that the light entrance surface is directed toward the first optical fiber. 15 The light receiving element is a back illuminated type semiconductor light receiving element.

[0026] The optical module further comprises a lead frame having an island and a plurality of lead terminals. The substrate is mounted on the island. 20

[0027] The optical module further comprises a resin containing the substrate, the semiconductor light emitting element, the light receiving element, and the 25 semiconductor driving element therein.

[0028] The foregoing and other objects, features and advantages of the invention will become more readily apparent from the following detailed description of a preferred embodiment of the invention 5 which proceeds with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] The teaching of the present invention can be readily understood in view of the following detailed 10 description with reference to the accompanying drawings provided for the illustrative purpose.

[0030] Fig. 1 is a view showing the primary components of the optical module in the first embodiment.

15 [0031] Fig. 2 is a view showing the substrate product of the optical module according to the embodiment.

[0032] Fig. 3 is a perspective view showing the optical module having a molded resin.

20 [0033] Fig. 4A is a sectional view, taken along line I-I in Fig. 3, showing the optical module having a molded resin. Fig. 4B is a sectional view showing the optical module with the resin partly cut away.

[0034] Fig. 5 is a perspective view showing the 25 optical module according to the embodiment.

[0035] Fig. 6 is a view showing the primary

components of the optical module in the second embodiment.

[0036] Fig. 7 is a view showing the substrate product of the optical module according to the 5 embodiment.

[0037] Fig. 8A is a sectional view showing the optical module sealed in the resin body. Fig. 8B is another sectional view showing the optical module with the resin body partly cut away.

10 [0038] Fig. 9 is a view showing the primary components of the optical module in the third embodiment.

15 [0039] Fig. 10 is a view showing the substrate product of the optical module according to the embodiment.

[0040] Fig. 11A is a sectional view showing the optical module sealed in the resin body. Fig. 11B is another sectional view showing the optical module with the resin body partly cut away.

20 [0041] Fig. 12A and Fig. 12B are views showing the optical device and the semiconductor light receiving device.

[0042] Fig. 13A and Fig. 13B are views showing a modification of the securing member.

25 [0043] Fig. 14A is a sectional view showing the optical module having a resin for molding. Fig. 14B

is a sectional view showing the optical module with the resin partly cut away.

[0044] Fig. 15 is a view showing an optical module having a multi-channel structure.

5 [0045] Fig. 16 is a view showing a multi-channel optical module having optical fibers.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

10 [0046] Subsequently, the embodiments of optical communication modules according to the present invention will be described with reference to the accompanying drawings. If possible, the same portions will be denoted by the same reference symbols.

[0047]

(First Embodiment)

15 Fig. 1 is a view showing primary components of the optical module according to an embodiment of the present invention. Fig. 2 is a view showing a substrate product of the optical module according to the embodiment of the present invention. With  
20 reference to Figs. 1 and 2, the substrate product 2a in the optical module 1a comprises a substrate 3, a semiconductor light emitting device 7, a semiconductor driving element 9, a mount member 13, an optical device 15, and a semiconductor light receiving device  
25 17.

[0048] The substrate 3 has a first region 3a and a

second region 3b. The first and second regions 3a, 3b are arranged in order along a predetermined plane. The substrate 3 is, for example, a silicon substrate and the width of the substrate 3 is approximately 2 to 5 millimeters, the length thereof is approximately 3 to 5 millimeters, and the thickness thereof is approximately 1 to 1.5 millimeters. The substrate 3 also has a first optical waveguide 3c and a second optical waveguide 3d. The first and second optical waveguides 3c, 3d are provided in the first region 3a and extend in a direction of a predetermined axis. Each of these optical waveguides 3c, 3d comprises a first cladding layer 5a provided on the substrate 3, a core layer 5b provided on the first cladding layer 5a, and a second cladding layer 5c provided on the core layer 5b. Each of the optical waveguides 3c, 3d has a structure including, for example, an SiO<sub>2</sub> film provided on the (100) silicon plane, an underclad SiO<sub>2</sub> layer provided on the SiO<sub>2</sub> film, an SiO<sub>2</sub>-GeO<sub>2</sub> core layer provided on the underclad SiO<sub>2</sub> layer, and an overclad SiO<sub>2</sub> layer provided on the core layer. The first optical waveguide 3c has ends 5d, 5e, and the second optical waveguide 3d has ends 5f, 5g. In a preferred example, the underclad SiO<sub>2</sub> layer has the thickness of approximately 10 micrometers and the overclad SiO<sub>2</sub> layer is the thickness of approximately 10

micrometers. The core layer has the width of approximately 6 micrometers and the thickness of approximately 6 micrometers. The illustrative structure of the substrate 3 has a base portion and an 5 optical waveguide portion provided on the base portion.

[0049] The semiconductor light emitting device 7 includes a semiconductor light emitting element 7a and is provided in the second region 3b of the substrate 10 3. The semiconductor light emitting device 7 may include, for example, a semiconductor laser element or a semiconductor optical amplifier. For example, the semiconductor light emitting element 7a emits light in the 1.3 micrometer wavelength band or 1.55 micrometer 15 wavelength band. The semiconductor light emitting element 7a has a pair of end faces 7b, 7c, and one end face 7b is optically coupled to one end 5g of the optical waveguide 3d. The optical reflectivity of one end face 7c is greater than that of the other end face 20 7b. If the semiconductor light emitting device 7 is a semiconductor laser element, the pair of end faces 7b, 7c form an optical cavity.

[0050] The semiconductor driving element 9 is mounted on mount member 13. The mount member 13 and 25 the substrate 3 are arranged along the predetermined plane. The semiconductor driving element 9 is

electrically connected through connecting member 11a, such as a bonding wire, to the semiconductor light emitting element 7. The semiconductor driving element 9 receives a pair of electric signals and generates a single drive signal from these electric signals. The single drive signal is applied to the semiconductor light emitting element 7a.

[0051] The optical device 15 includes an optical element 15a capable of reflecting a part of incident light and another part of transmitting part of the incident light. The optical element 15a may be, for example, an optical filter. The optical element 15a is provided between first optical waveguide 3c and second optical waveguide 3d. The optical element 15a includes a transparent substrate 15b through which the light emitted by the semiconductor light emitting element 7a can pass. The transparent substrate 15b has a pair of surfaces 15c, 15d, each extending along a surface intersecting with the predetermined axis, and one surface 15c transmits a part of the incident light and reflects another part of the incident light. One surface 15c faces one end 5f of the optical waveguide 3d and is optically coupled to one end 5f of the optical waveguide 3d. The other surface 15d faces one end 5e of the optical waveguide 3c and is optically coupled to one end 5e of the optical

waveguide 3c.

[0052] The semiconductor light receiving device 17 includes a light receiving element 17a mounted in the first region 3a so as to be optically coupled to the optical element 15a. The light receiving element 17a receives a part of the light from the semiconductor light emitting element 7a through optical waveguide 3d and the optical element 15a. The remaining part of the light passes through the optical element 15a and enters the optical waveguide 3c. The optical device 15 is positioned with respect to the substrate 3, and the semiconductor light receiving device 17 is positioned with respect to the substrate 3. Thus, the optical device 15 is positioned with respect to the semiconductor light receiving device 17. This positioning enables the semiconductor light receiving device 17 to monitor the light from the semiconductor light emitting element 7a.

[0053] Since the light receiving element 17a can be provided in the first region 3a of the substrate 3, the distance between the substrate 3 and the mount member 13, mounting the semiconductor driving element 9, can be small, so that the distance between the semiconductor driving element 9 and the semiconductor light emitting element 7 become small and the light receiving element 17a can receive the forward light of

the semiconductor light emitting element 7 through the optical waveguide 3d on the substrate 3.

[0054] The light receiving element 17a has light entrance surface 17b which receives the light from the 5 optical element 15a. The light receiving element 17a is provided such that the light entrance surface 17b extends along a plane extending in a direction in which the primary surface of the substrate 3 extends. The light receiving element 17a can be, for example, a 10 back illuminated type semiconductor light receiving element.

[0055] The optical module 1a may be further provided with a lead frame 21. The lead frame 21 has an island 21a and a plurality of lead terminals 21b. 15 The substrate 3 is mounted on the island 21a. The primary surface of the island 21a has a first portion 21c and a second portion 21d. The first portion 21c and second portion 21d are arranged in the direction of the predetermined axis. The substrate 3 and the 20 mount member 13 are arranged in the direction of the predetermined axis on the island 21a. The substrate 3 is mounted on the first portion 21c and the mount member 13 is mounted on the second portion 21d. The island 21a has a pair of edges 21e, 21f, some of the 25 lead terminals 21b are arranged such that one ends of these lead terminals 21b face the edge 21e, and others

of the lead terminals 21b are arranged such that one ends of these lead terminals 21b face the edge 21f. The lead frame 21 enables electrical connections among the semiconductor light emitting element 7, light receiving element 17 and semiconductor driving element 9, and enables the mounting of the substrate 3 and the mount member 13.

[0056] Referring to Fig. 2, the semiconductor driving element 9 is connected through a pair of connecting members 11b, such as bonding wires, to the lead terminals 21b. The semiconductor light emitting device 7 has an anode and a cathode, and one of the anode and cathode receives a drive signal from the semiconductor driving element 9 through the connecting member 11a and receives power through the connecting members 11c and 11d. The semiconductor light receiving device 17 has an anode and a cathode, and one of the anode and cathode provides a photocurrent through connecting member 11e and receives power through connecting members 11f and 11g.

[0057] Referring back to Figs. 1 and 2, the substrate 3 in optical module 1a has a groove 23. The groove 23 is positioned with respect to the light receiving element 17a and extends so as to intersect with the optical transmission path constituted by the optical waveguides 3c and 3d. The substrate 3 has a

pair of edges 3e and 3f, each extending in the direction of the predetermined axis. The groove 23 extends from one edge 3e of the pair of edges to the other edge 3f and extends along a reference plane intersecting with the predetermined surface. This reference plane intersects with the primary surface of the substrate 3 so as to make an acute angle therewith referred as Symbol  $\alpha$  (alpha). The optical device 15 is provided in the groove 21. The symbol  $\alpha$  (alpha) indicating the inclination of the groove 23 shows the angle that the optical element 17a forms with the optical transmission path constituted by the optical waveguides 3c and 3d. In a preferred example, the angle which the primary surface of the substrate 3 forms with the light entrance surface of optical element 15a is preferably in the range of not less than 45 degrees and not more than 75 degrees, and is more preferably approximately 60 degrees within this range. If the angle falls within the range, the optical module 1a has the advantage that the reflected light easily enters the light receiving element 17a.

[0058] Fig. 3 is a perspective view showing an optical module contained in a sealing resin. Fig. 4A is a cross-sectional view, taken along line I-I in Fig. 3, showing this optical module. Fig. 4B is a cross-sectional view showing the optical module with

the resin cut away partly. Referring to Fig. 4A, the substrate product 2a may further comprise a transparent resin 25, an optical device 15 and a light receiving device 17. The transparent resin 25 is provided on the substrate 3 so as to cover the semiconductor light emitting device 7. The transparent resin 25 is made of material through which light emitted by the semiconductor light emitting device 7 can pass. The transparent resin 25 can protect the semiconductor light emitting device 7, optical device 15, and light receiving device 17 from the sealant resin 33 and can maintain the optical coupling among the semiconductor light emitting device 7, the optical device 15 and the light receiving device 17.

[0059] Referring to Fig. 3 and Figs. 4A and 4B, the optical module 1a further comprises a ferrule product 31. The ferrule product 31 includes an optical fiber 27 and a ferrule. The optical fiber 27 is optically coupled to the optical waveguide 3c of substrate product 2a and the ferrule 29 holds the optical fiber 27. The optical module 1a includes the substrate product 2a, the lead frame 21, the ferrule product 31, and the resin 33. The resin 33 serves to protect the substrate 3, semiconductor light emitting device 7, semiconductor driving element 9, and light receiving

device 17. The outer shape of the resin 33 is formed by a molding die for the optical module.

[0060] Fig. 5 is a perspective view showing the optical module in the present embodiment. The optical module 1a has the resin 33, and the lead terminals 21b are arrayed on one side 33a and the opposed side 33b of the resin 33. One end of the ferrule product 31 projects out through the front face 33c of the head portion of the resin 33. The molded resin 33 has projections 33d, 33e, working to engage an optical connector therewith, provided on the both sides of the head part thereof.

[0061]

(Second Embodiment)

Fig. 6 is a view showing components of an optical module according to another embodiment of the present invention. Fig. 7 is a view showing a substrate product of the optical module according to the embodiment. Referring to Figs. 6 and 7, the substrate product 2b in the optical module 1b comprises a substrate 4, a semiconductor light emitting device 7, a semiconductor driving element 9, an optical device 16, and a semiconductor light receiving device 17.

[0062] The optical module 1b has the substrate 4 instead of the substrate 3 of optical module 1a. Subsequently, the substrate 4 will be described in

detail. The substrate 4 has a first region 4a, a second region 4b, and a third region 4c. The first to third regions 4a, 4b, 4c are arranged in order along a predetermined plane. The substrate 4 may be, for example, a silicon substrate. The substrate 4 has a first optical waveguide 4d and a second optical waveguide 4e. The first and second optical waveguides 4d, 4e are provided in the first region 4a and extend in a direction of a predetermined axis. The first optical waveguide 4d has a pair of ends 5d and 5e, and the second optical waveguide 3e a pair of ends 5f and 5g. The structures of these optical waveguides 4d and 4e may be similar to those of the optical waveguides in the first embodiment. The semiconductor driving element 9 is mounted in the third region 4c of the substrate 4.

[0063] In the optical module 1b, the substrate 4 has a groove 24. The structure of the groove 24 may be similar to that in the first embodiment. The groove 24 is positioned with respect to the light receiving element 17a and extends so as to intersect with the optical transmission path constituted by the optical waveguides 4d and 4e. The groove 24 extends from one edge 4f of the pair of edges to the other edge 4g and extends along a reference plane intersecting with the predetermined plane. The

reference plane extending along the groove 24 intersects with the primary surface of the substrate 4 so as to make an acute angle  $\beta$  (beta) which the groove 24 forms with the above primary surface of the substrate 4. The optical device 15 is provided in the groove 24. The symbol  $\beta$  (beta) indicating the inclination of the groove 24 shows the angle that the optical element 17a forms with the optical transmission path constituted by the optical waveguides 4d and 4e.

[0064] The optical device 16 includes an optical element 16a capable of reflecting a part of incident light and transmitting another part of the incident light. The optical element 16a is provided between the first optical waveguide 4d and the second optical waveguide 4e. The optical element 16a includes a transparent substrate 16b through which the light generated by the semiconductor light emitting element 7a can pass. The transparent substrate 16b has a pair of surfaces 16c and 16d, each extending along a plane intersecting with the predetermined axis. A dielectric multi-layer film 16e is provided on one of the pair of surfaces 16c and 16d. In the optical device 16, one surface 16c transmits one part of the incident light and reflects another part of the incident light. One surface 16c faces one end 5f of

the optical waveguide 4e and is optically coupled to one end 5f of optical waveguide 4e. The other surface 16d faces one end 5e of the optical waveguide 4d and is optically coupled to one end 5e of the optical waveguide 4d.

[0065] The optical module 1b may further comprise a lead frame 22. The lead frame 22 has an island 22a and a plurality of lead terminals 22b. The lead frame 22 mounts the substrate 4. The substrate 4 is provided on the island 22a in contrast to that of the optical module 1a of the first embodiment. The island 22a has a pair of edges 22e and 22f, some of the lead terminals 22b are arranged such that one ends of the lead terminals 22b face the edge 22e, and others of the lead terminals 22b are arranged such that one ends of the lead terminals 22b face the edge 22f. The lead frame 22 serves to electrically connect the semiconductor light emitting element 7, light receiving element 17, and semiconductor driving element 9 with each other, and to mount the substrate 4.

[0066] In the optical module 1b, the light receiving element 17a receives a part of light from the semiconductor light emitting element 7a through the optical waveguide 4e and the optical element 15a. The remaining of the light from the semiconductor

light emitting element 7a enters the optical waveguide 4d. The optical device 16 is positioned with respect to the substrate 4, and the semiconductor light receiving device 17 is positioned with respect to the optical device 16 on the substrate 4, so that the optical device 16 can be positioned with respect to the semiconductor light receiving device 17.

[0067] As shown in Figs. 8A and 8B, the optical module 1b is also sealed in the resin 33 as in the case of the optical module 1. A ferrule product 31 is optically coupled to the optical waveguide 4d and projects out through one end face of the resin 33.

[0068] In the present embodiment, the substrate product 2b can be obtained by mounting the semiconductor light emitting device 7, the semiconductor driving element 9, the optical device 16, and the light receiving device 17 on the substrate 4. This structure can decrease the number of constituent components of the optical module and thus facilitate the assembly of the optical module. The optical module 1b does not need an assembly margin between the substrate and the mount member mounting the semiconductor driving element thereon, so that the distance between the semiconductor driving element 9 and the semiconductor light emitting device 7 can be decreased.

[0069]

(Third Embodiment)

Fig. 9 is a view showing the components of an optical module in still another embodiment of the present invention. Fig. 10 is a view showing a substrate product of the optical module according to the embodiment. Referring to Figs. 9 and 10, the substrate product 2c of optical module 1c comprises a substrate 35, a semiconductor light emitting device 5, a semiconductor driving element 9, an optical device 15, a semiconductor light receiving device 17, a first optical fiber 37, and a second optical fiber 39. The second optical fiber 39 is held by ferrule 41.

[0070] The substrate 35 has a first region 35a, a second region 35b, and a third region 35c. The first to third regions 35a to 35c are arranged in order along a predetermined plane. The substrate 35 may be, for example, a silicon substrate, as in the first and second embodiments. The substrate 35 comprises a support groove 35d for supporting the first optical fiber 37, a support groove 35e for supporting the second optical fiber 39, and a support groove 35f for ferrule 41. In the substrate 35, the support groove 35d, the support groove 35e, and the support groove 35f extend in the direction of a predetermined axis. The support groove 35d has a first support face 43a

and a second support face 43b. The support groove 35e has a third support face 43c and a fourth support face 43d. The support groove 35f has a fifth support face 43e and a sixth support face 43f. These support 5 grooves can be formed, for example, by use of a silicon wafer together with a photolithography technology and a wet etching technology.

[0071] The substrate 35 has a groove 43 provided between the second region 35b and the third region 10 35c. The groove 43 extends from one side of a pair of sides 35g and 35h to the other side. The groove 43 has an abutting face 43a provided at one end of support groove 35d. The abutting face 43a intersect with the predetermined axis. One end 37a of optical 15 fiber 37 is provided in the groove 43 so as to abut against the abutting face 43a. The substrate 35 has a groove 45 provided between the support groove 35e and the support groove 35f.

[0072] In the optical module 1c, the substrate 35 20 has a groove 47 provided between the support groove 35d and the support groove 35e. The groove 47 is positioned with respect to the light receiving element 17a and extends so as to intersect with the optical transmission path constituted by the optical fibers 37 25 and 39. The groove 47 extends from one side of the pair of sides 35g and 35h to the other side and

extends along a reference plane intersecting with the primary surface of the substrate 35. The optical device 15 is inserted in the groove 47. The symbol  $\gamma$  (gamma) indicating the inclination of the groove 47 is defined by an angle which the light entrance surface of the optical element 15a forms with the optical transmission path constituted by the optical fibers 37 and 39. In the present embodiment, the groove 47 makes an acute angle with the primary surface of substrate 35.

[0073] The semiconductor light emitting device 7 includes a semiconductor light emitting element 7a and is provided in the second region 35b of the substrate 35. The semiconductor light emitting device 7 has a pair of end faces 7a and 7b and one end face 7a is optically coupled to one end 37a of the optical fiber 37 abutting against the face 43a.

[0074] The semiconductor driving element 9 is mounted on the first region 35a. The semiconductor driving element 9 is electrically connected through a connecting member 12a, such as a bonding wire, to the semiconductor light emitting element 7a.

[0075] In the optical device 15, the optical element 15a is provided between the first optical fiber 37 and the second optical fiber 39. The optical element 15a has a pair of surfaces 15c and 15d, each

extending along a plane intersecting with the predetermined axis. One surface 15c transmits one part of the incident light and reflects another part of the incident light. One surface 15c faces one end 5 37b of the optical fiber 37 and is optically coupled to one end 37b of the optical fiber 37. The other surface 15d faces one end 39a of the optical fiber 39 and is optically coupled to one end 39a of the optical fiber 39.

10 [0076] The semiconductor light receiving device 17 includes a light receiving element 17a. The light receiving element 17a is mounted in the second region 35c so as to be optically coupled to the optical element 15a. The semiconductor light receiving device 15 17 is mounted on the mount component 49 and is located above the optical fiber 37. Namely, the optical fiber 37 is located between the semiconductor light receiving device 17 and the substrate 35. The mount component 49 serves as a securing member which can be used to secure the optical fiber 37. The light receiving element 17a receives a part of light from the semiconductor light emitting element 7a through the optical fiber 37, the optical element 15a and the mount component 49. The remaining of the light from 20 25 semiconductor light emitting element 7a is supplied to optical fiber 39. The optical device 15 is positioned

with respect to the substrate 35, and the semiconductor light receiving device 17 is positioned with respect to the substrate 35, so that the semiconductor light receiving device 17 is positioned  
5 with respect to the optical device 15.

[0077] The optical fiber 37 is located between the mount component 49 and the substrate 35. The mount component 49 is made of material through which light emitted by the semiconductor light emitting device 7 can pass. The mount component 49 comprises a surface 49a and a positioning surface 49b. The surface 49a is provided for mounting of the semiconductor light receiving device 17, and the positioning surface 49b is provided for positioning the optical fiber 37. The  
10 light receiving element 17a is provided such that the light entrance surface 17b thereof is directed toward  
15 the mount surface 49a.

[0078] The light receiving element 15a is provided in the third region 35c of the substrate 35 and the semiconductor driving element 9 is provided in the first region 35a of substrate 35, so that the distance between the semiconductor driving element 9 and the semiconductor light emitting element 7 can be shortened and the light receiving element 17a can receive the forward light of semiconductor light emitting element 7a through optical fiber 37.  
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[0079] Fig. 11A is a sectional view showing an optical module sealed with a resin. Fig. 11B is another sectional view showing the optical module with the sealing resin of the optical module partly cut away. Referring to Figs. 11A and 11B, the substrate product 2c may further comprise a transparent resin 26 through which light emitted by the semiconductor light emitting device 7 can pass, as in the case of the optical modules in the first and second embodiments. The transparent resin 26 of the substrate product 2c is provided on the substrate 35 so as to cover the semiconductor light emitting device 7, the optical device 15, and the light receiving device 17.

[0080] Referring to Figs. 11A and 11B, the optical module 1c comprises a substrate product 2c, a lead frame 22, a ferrule product 51, and a resin 53. The ferrule product 51 includes an optical fiber 39 and a ferrule 41.

[0081] Figs. 12A and 12B are views showing the optical coupling among the optical fibers, the optical device, and the semiconductor light receiving device. With reference to Fig. 12A, the semiconductor light receiving device 17 can be a back illuminated type photodiode. The light "A" from semiconductor light emitting element 7a travels through the optical fiber 37 and then enters the optical element 15a. A part of

the light "A" becomes light "B" traveling through the mount component 49 into the light receiving element 17a. The remaining of the light "A" becomes light "C" traveling through the optical element 15a into the 5 optical fiber 39. Referring to Fig. 12B, the semiconductor light receiving device 18 can be a front illuminated type photodiode. The light "A" from semiconductor light emitting element 7a travels through the optical fiber 37 and then enters the 10 optical element 15a. A part of the light "A" becomes light "D" traveling through the mount component 49 through which the light "A" can pass, and then enters the light receiving element 18a. The remaining of the light "A" becomes light "E" that travels through the 15 optical element 15a and then enters the optical fiber 39. For example, the distance between the semiconductor light receiving device 17 and the optical element 15a in Fig. 12A can be greater than the distance between the semiconductor light receiving 20 device 18 and the optical element 15a in Fig. 12B. The mount component 49 can be used for securing the optical fiber.

[0082] Figs. 13A and 13B are views showing a modification of the mount component. Referring to 25 Fig. 13A, the mount component 50 has an aperture 50a. The aperture 50a is positioned to the light receiving

element of the semiconductor light receiving device. Light from semiconductor light emitting element 7a travels via the optical fiber 37, optical element 15a, and aperture 50a and then enters the light receiving 5 element 17a. The mount component 50 obviates the necessity of the mount component 50 made of material that can transmit light from the semiconductor light emitting element 7a. The mount component 50 can be used for securing the optical fiber.

10 [0083] In the present embodiment, although the semiconductor driving element 9 is mounted on the substrate 35, the semiconductor driving element 9 can be mounted on the mount member 13 as shown in the first embodiment.

15 [0084] The substrate 35 has some grooves, intersecting with the direction in which the optical fibers extend, in addition to the support grooves. These grooves can be formed, for example, with a dicing tool.

20 [0085]

(Fourth Embodiment)

Fig. 14A is a sectional view showing a resin-molded optical module. Fig. 14B is another sectional view showing the optical module with the resin of the 25 optical module partly cut away. Referring to Figs. 14A and 14B, the substrate product 2d of optical

module 1d comprises a substrate 63, a semiconductor light emitting device 67, a semiconductor driving element 69, an optical device 65, and a semiconductor light receiving device 77.

5 [0086] The substrate 63 has a first region 63a, a second region 63b, and a third region 63c. The first to third regions 63a, 63b, 63c are arranged in order along a predetermined plane. The substrate 63 may be, for example, a silicon substrate. The substrate 63 has a first optical waveguide 63d and a second optical waveguide 63e, a third optical waveguide 63f and a fourth optical waveguide 63g, a fifth optical waveguide 63h and a sixth optical waveguide 63i, and a seventh optical waveguide 63j and an eighth optical waveguide 63k. The first to eighth optical waveguides 63d to 63k are provided in the first region 63a and each of these optical waveguides 63d to 63k extends in a direction of a first axis. The first optical waveguide 63d and second optical waveguide 63e, the third optical waveguide 63f and fourth optical waveguide 63g, the fifth optical waveguide 63h and sixth optical waveguide 63i, and the seventh optical waveguide 63j and eighth optical waveguide 63k are arranged in order in a direction of a second axis 20 perpendicular to the first axis.

25 [0087] The description hereinafter concerns the

first optical waveguide 63d and second optical waveguide 63e, but the other optical waveguides 63f to 63k also have structures similar thereto. The first optical waveguide 63d has a pair of ends 63m and 63n, 5 and the second optical waveguide 63e has a pair of ends 63p and 63q. The structures of these optical waveguides 63d and 63e may be similar to those of the optical waveguides in the first embodiment. The semiconductor driving element 69 is mounted in the 10 third region 63c of the substrate 63.

[0088] The semiconductor light emitting device 67 is provided in the second region 63b of the substrate 63 and includes a plurality of semiconductor light emitting elements 67a to 67d. These semiconductor light emitting elements can be, for example, semiconductor laser elements or semiconductor optical amplifiers. Although the description hereinafter concerns the semiconductor light emitting element 67a, the other semiconductor light emitting elements 67b to 15 67d also have a similar structure. The semiconductor light emitting element 67a has a pair of end faces 67e and 67f, and one end face 67e is optically coupled to one end 63q of the optical waveguide 63e. The optical reflectivity of one end face 67e is smaller than that 20 of the other end face 67f. If the semiconductor light emitting element 67a works as a semiconductor laser 25

element, the pair of end faces 67e and 67f constitute an optical cavity.

[0089] The semiconductor driving element 69 is provided in the third region 63c of the substrate 63. 5 The semiconductor driving element 69 is electrically connected through connecting members 71a, such as bonding wires, to the semiconductor light emitting elements 67a to 67d, respectively. The semiconductor driving element 69 receives a pair of electric signals 10 for each of the semiconductor light emitting elements 67a to 67d and generates a single drive signals for each of the semiconductor light emitting elements 67a to 67d from the pair of electric signals. The single drive signal is applied to each of the semiconductor 15 light emitting elements 67a to 67d.

[0090] The optical device 65 includes optical elements 65a to 65d that can reflect a part of incident light and transmitting a part of the incident light. The optical elements 65a to 65d are provided 20 on single substrate 65e and are aligned with the locations of the optical waveguides on the substrate 63, respectively. Each of the optical elements 65a to 65d may have the structure of the optical element 15a in the first embodiment or the optical element 16a in 25 the second embodiment, but is not limited to this structure.

[0091] In the optical module 1d, the substrate 63 has a groove 28 of a structure similar to that in the first embodiment. The groove 28 is positioned with respect to the light receiving device 77 and extends so as to intersect with an optical transmission path constituted by the optical waveguides 63d and 63e (similarly, with optical transmission paths constituted by the other optical waveguides). The reference plane extending along the groove 28 intersects with the primary surface of the substrate 63 so as to make an obtuse angle  $\delta$  (delta) therewith. The optical device 65 is provided in the groove 28. The symbol  $\delta$  (delta) showing the inclination of the groove 28 indicates an angle between the optical element 65a and the optical transmission path.

[0092] The semiconductor light receiving device 77 is mounted in the first region 63a. The semiconductor light receiving device 77 includes light receiving elements 77a to 77d. The light receiving elements 77a to 77d are arranged to be optically coupled to the optical elements 65a to 65d, respectively. Each of the light receiving elements 77a to 77d may have a structure equivalent or similar to the light receiving elements used in the optical modules in the first to third embodiments, but is not limited to this. The semiconductor light receiving device 77 has a single

substrate 77e and the light receiving elements 77a to 77d are provided in the substrate 77e. The locations of these light receiving elements 77a to 77d are aligned with those of the optical waveguides on the 5 substrate 63. The optical device 65 is positioned with respect to the substrate 63, and the semiconductor light receiving device 77 is positioned with respect to the substrate 63. As a consequence, the semiconductor light receiving device 77 is 10 positioned with respect to the optical device 65.

[0093] In the substrate product 2d and optical module 1d of the present embodiment, the light receiving element 77a is provided on the first region 63a of substrate 63 and the semiconductor driving element 69 in the third region 63c of substrate 63, so 15 that the distance between the semiconductor driving element 69 and the semiconductor light emitting device 67 can be shorten and the light receiving elements of semiconductor light receiving device 77 receives the forward light of the semiconductor light emitting device 67 through the optical waveguides in substrate 63 and via 20 the optical elements of the optical device 65, respectively.

[0094] The optical module 1d may further comprise a 25 lead frame 73. The lead frame 73 has an island 73a .

and a plurality of lead terminals 73b and 73c. The island 73a is provided for mounting the substrate 63. The lead terminals 73b and 73c are located on three sides of the primary surface of the island 73a. The  
5 lead frame 73 serves to make electrical connections among the semiconductor light emitting device 67, the light receiving device 77, and the semiconductor driving element 69. Also, the lead frame 73 serves to mount the substrate 63.

10 [0095] The semiconductor driving element 69 is connected through a pair of connecting members 71b and 71c, such as bonding wires, to the lead terminals 73b. Each semiconductor light emitting element of the semiconductor light emitting device 67 has an anode and a cathode. One of the anode and cathode receives a drive signal from the semiconductor driving element 69 through the connecting member 71a and receives power through the connecting members 71d. Each light receiving element of the semiconductor light receiving device 77 has an anode and a cathode. One of the anode and cathode provides a photocurrent through the connecting member 71e and receives power through the connecting members 71f.  
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[0096] With reference to Figs. 14A and 14B, the substrate product 2a may further comprise a transparent resin 75 provided on the substrate 63 so  
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as to cover the semiconductor light emitting device 67, the optical device 65, and the light receiving device 77. The transparent resin 75 is made of material through which light emitted by the 5 semiconductor light emitting device 67 can pass. The transparent resin 75 can protect the semiconductor light emitting device 67, the optical device 65, and the light receiving device 77 from the sealant resin and can maintain the optical coupling among the 10 semiconductor light emitting device 67, the optical device 65, and the light receiving device 77. The optical module 1d comprises an optical fiber ribbon 79 optically coupled to the optical waveguide 63d, 63f, 63h, 63j of the substrate product 2d. The optical 15 module 1d comprises the substrate product 2d, the lead frame 73, the optical fiber ribbon 79, and the molded resin 81. The resin 81 serves to protect the substrate 63, the semiconductor light emitting device 67, the semiconductor driving element 69, and the 20 light receiving device 77. The outer shape of the resin 81 can be formed by a molding die for the optical module.

[0097] The optical module 1d is sealed in the resin 81. Referring to Fig. 15, the optical fiber ribbon 25 79, optically coupled to the optical waveguides 63d, 63f, 63h, 63j, projects out through one end face of

resin body 81.

[0098] In the present embodiment of the substrate product 2d, the semiconductor light emitting device 67, the semiconductor driving element 69, the optical device 65, and the light receiving device 77 are mounted on the substrate 63. This structure can decrease the number of constituent components for the optical module and facilitate the assembly of the optical module. Since there is no need for an assembly margin between the substrate and the mount member that mounts the semiconductor driving element, the optical module 1d can decrease the distance between semiconductor driving element 69 and semiconductor light emitting device 67.

[0099] The substrate includes the optical waveguides in the present embodiment, and it is thought by a person skilled in the art from the embodiments described before the present embodiment that the substrate 36 having a plurality of grooves 36d, 36e for supporting optical fibers 64d to 64k, as shown in Fig. 16, can be used instead of the substrate 63 in the present embodiment. The substrate 36 also has first to third regions 36a to 36c arranged along the predetermined axis, as in the above-described embodiment. The optical fibers 64d, 64f, 64h, 64j are held by ferrule 42 and the ferrule 42 is located in

groove 36f. The illustration of the connecting members, such as bonding wires, is omitted from Fig. 16 for simplicity.

[0100] In the optical module and substrate product 5 of the present embodiment, as described above, when the amount of the forward light of the semiconductor light emitting device (e.g., 1 milliwatt) and the optical reflectivity R of the optical device (e.g., 10 percent) are estimated, the output photocurrent of the 10 light receiving device (e.g., 100 microamperes) is determined independent of the optical reflectivity of the back surface of the semiconductor light emitting device. Namely, the monitoring photocurrent value is stabilized.

[0101] In the optical module and substrate product 15 of the present embodiment, although the forward light of the semiconductor light emitting device fluctuates with change in ambient temperature even under an APC operation in response to the monitor current from the 20 semiconductor light receiving device, the optical module and substrate product of the present embodiment decreased the tracking error due to the fluctuation of the forward light.

[0102] In optical modules and substrate products 25 used heretofore by the present inventors, monitor current from a monitoring photodiode varies in the

range of approximately one order of magnitude (for example, 100 microamperes to 1000 microamperes) because of the following reasons: variation in optical coupling efficiency between the front face of a 5 semiconductor light emitting device and an optical waveguide or optical fiber; and because of variation in optical coupling efficiency between the rear face of the semiconductor light emitting device and the monitoring photodiode.

10 [0103] Even under the APC operation, optical coupling efficiency between the front face of a semiconductor light emitting device and an optical waveguide or optical fiber varies with change in temperature. This variation results in fluctuation in 15 the ratio of the forward light to the monitor light. According to the inventors' estimation, the fluctuation of the forward light is in a range of approximately ±20 percent to ±40 percent.

[0104] However, the optical module and substrate 20 product of the present embodiment can decrease the variations and fluctuations as described above.

[0105] The present invention has been 25 illustratively described as above with the embodiments thereof. According to the embodiments, the semiconductor light emitting device can be located in the vicinity of the semiconductor driving element on

the substrate. Therefore, the impedance can be low between the semiconductor driving element and the semiconductor light emitting device. The optical module and substrate product of the preferred example 5 can achieve the transmission rates of approximately 1 to 5 Gigabits per second (Gb/s). Since the surface mounting technology can be used to the assembly of most components for the optical modules and substrate products of the embodiments, it is feasible to mount 10 these components within a smaller mounting region and simplify the assembly steps. The optical modules of the embodiments may be single channel optical modules or multiple channel optical modules.

[0106] As described above, the present invention 15 has provided the optical modules of the structure capable of containing the driving element therein which supplies the drive signal to the semiconductor light emitting element.

[0107] Having described and illustrated the 20 principle of the invention in a preferred embodiment thereof, it is appreciated by those having skill in the art that the invention can be modified in arrangement and detail without departing from such principles. For example, the optical device can be 25 provided to reflect a part of incident light in a predetermined wavelength band and transmit a part of

the incident light in the band. The optical device having an optical spectrum in which the reflectivity outside the predetermined wavelength band is greater than that in the predetermined wavelength band may be included. We therefore claim all modifications and variations coming within the spirit and scope of the following claims.